LHC Collimator R&D

Eric Doyle, Josef Frisch, Tom Markiewicz, Tor Raubenheimer
SLAC

LARP

Port Jefferson NY

17 September 2003

Recent History

- **Jim Strait mentions LHC Beam-Abort Failure collimator survival problem @ SLAC "Futures" seminar in 4/2003. NLC** consumable collimators **seem to be ideal solution.**

- **Ralph Assmann contacted; visits SLAC May 2003**
  - **Emails w/ Ralph, Lyn Evans, Peter Sievers for technical specs**
  - **Discussions with Jean-Bernard Jeanneret (Lattice Designer) & Rudiger Schmidt (LHC MPS czar) at HALO'03**

- **While NLC** consumable design with flexible cooling hoses **seems feasible, CERN decides to stay with baseline design for Phase 1 running and install new collimators, if necessary, as current & luminosity rises**

- **Discussions with Assmann et al, LARP, DOE, & SLAC management on desire, appropriateness, resources, … of adapting SLAC consumable concept for LHC Phase II**
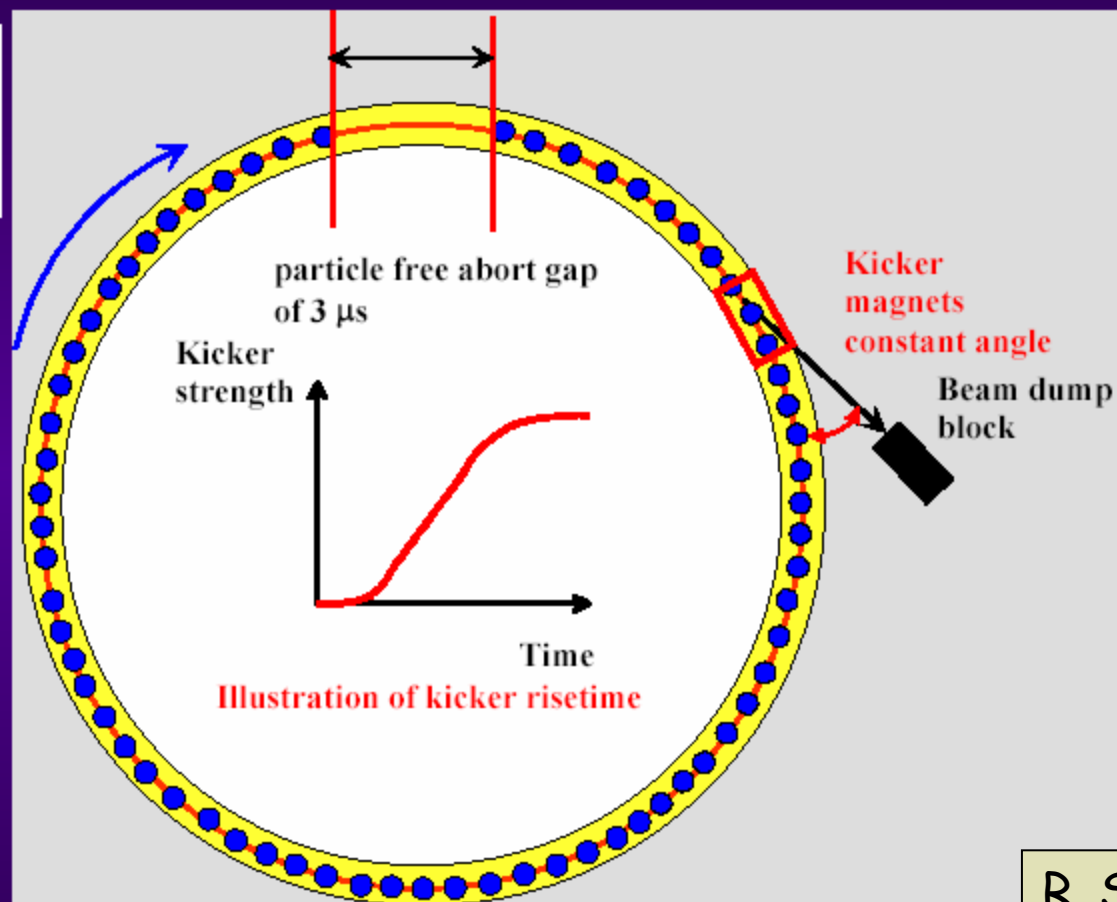
Beam Dump Abort System

Requirement for clean beam dump

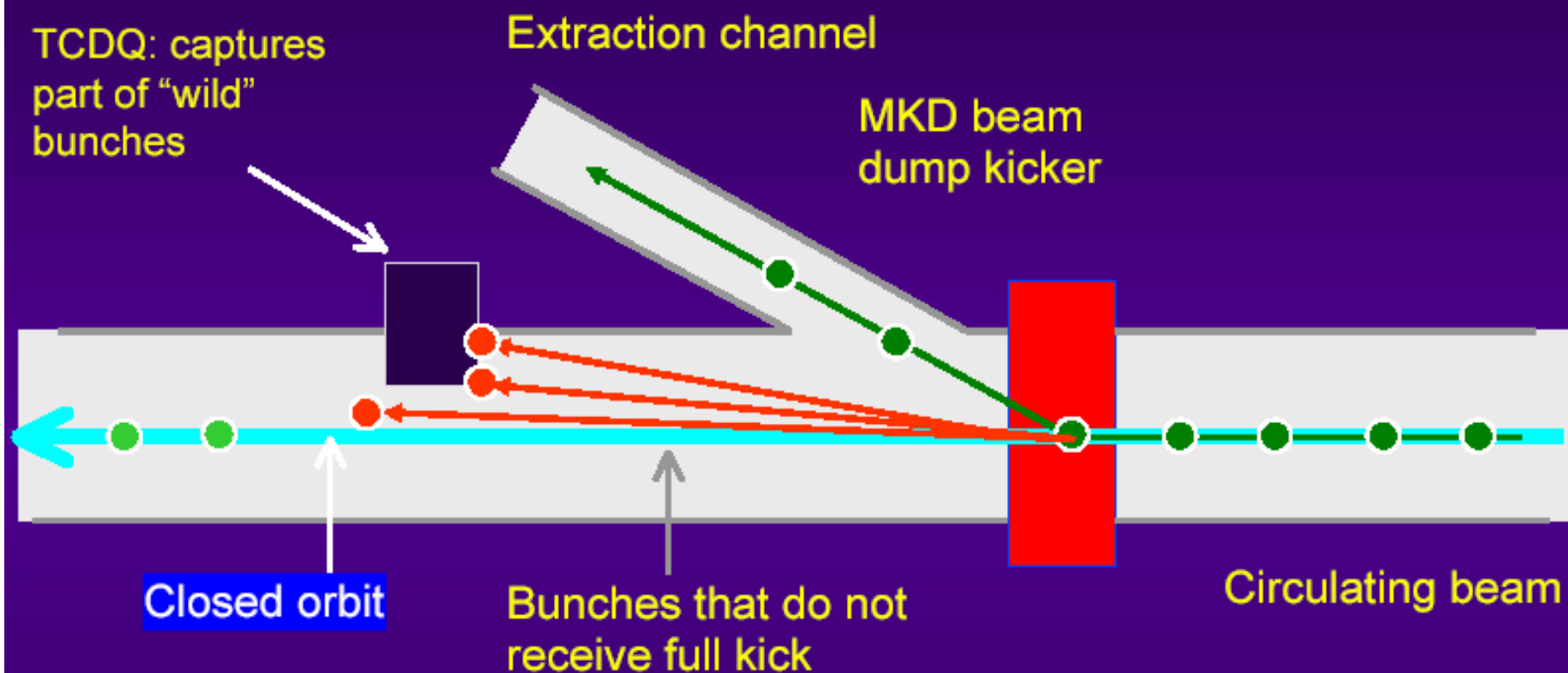Beam dump must be **synchronised** with particle free gap

Strength of kicker and septum magnets must **match energy** of the beam

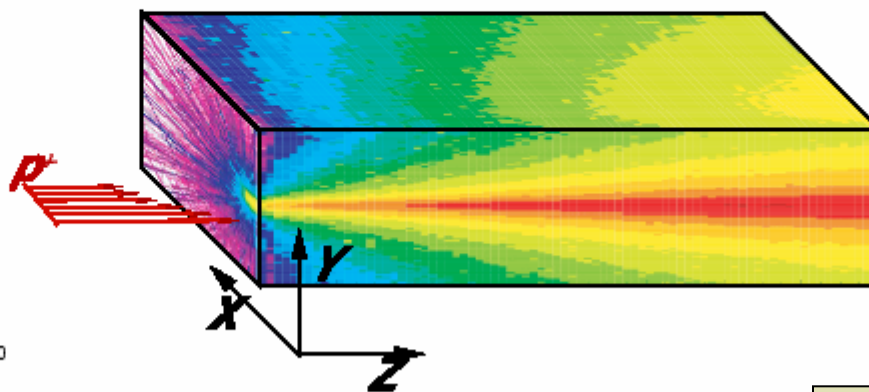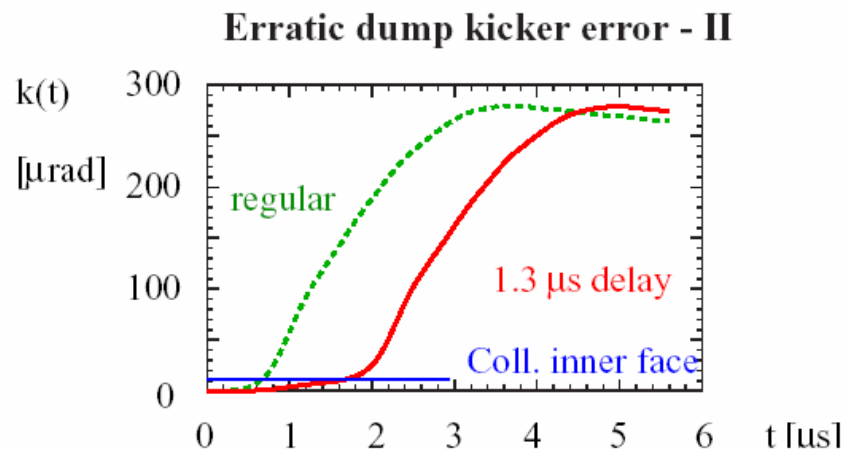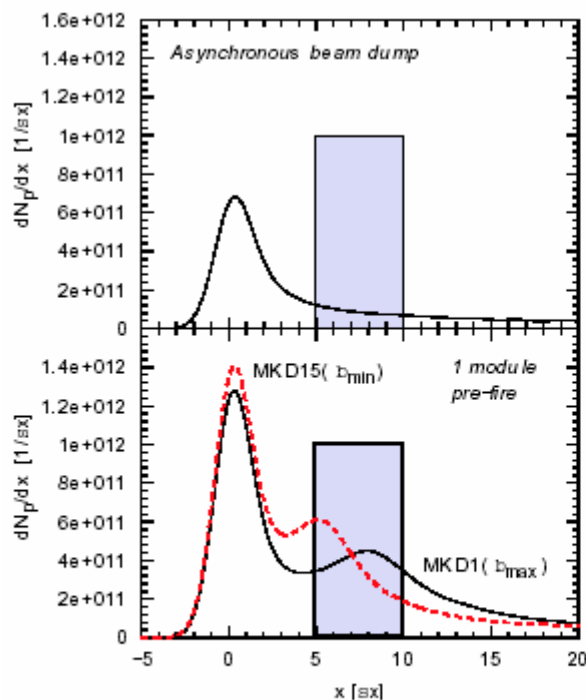« Particle free gap » must be **free of particles**

particle free abort gap of 3 µs

Kicker strength

Time

Illustration of kicker risetime

Kicker magnets constant angle

Beam dump block

R. Schmidt

HALO '03

Beam Dump Kicker Failure

R. Schmidt

HALO '03

 # Bunches on Collimators ∝ Delay in Retriggering Dump Kicker

Δt now < ~0.7 μs ⇒
8 bunches on colls

Erratic dump kicker error - II

$k(t)$
[μrad]

regular

1.3 μs delay

Coll. inner face

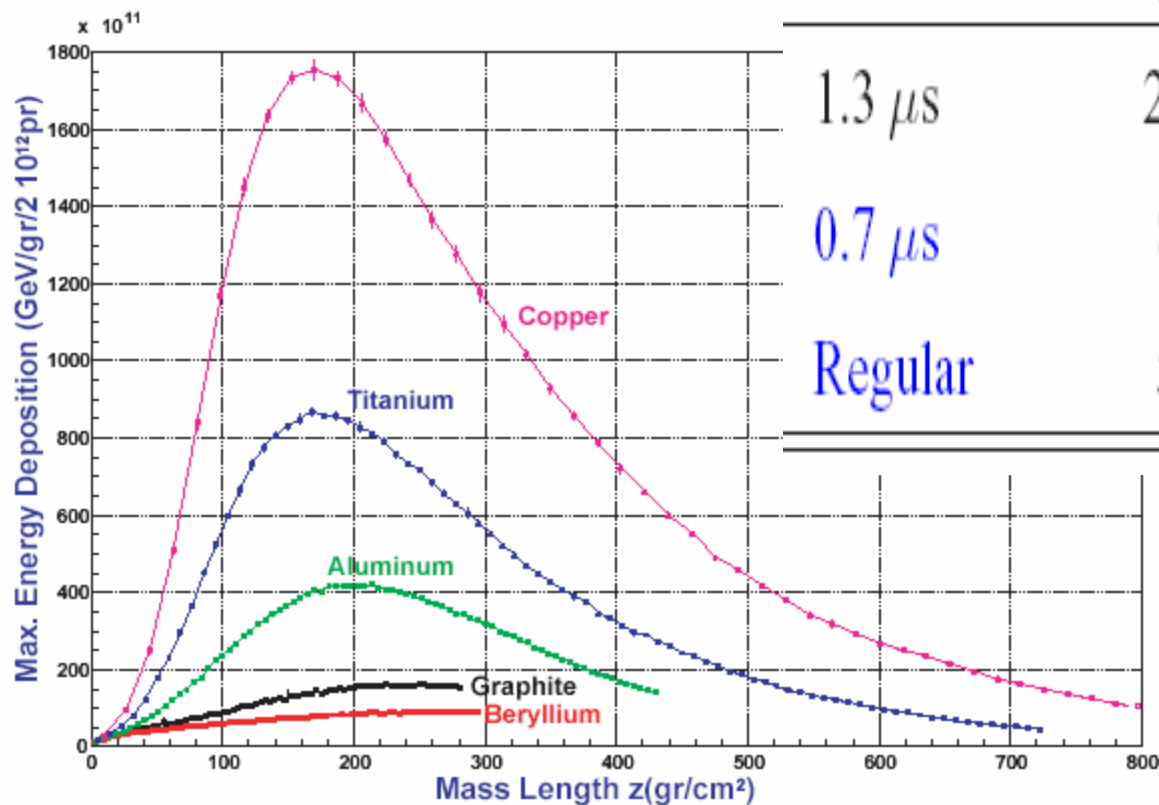Asynchronous beam dump

MKD15(b_{min})   1 module pre-fire

MKD1(b_{max})

FLUKA → 3D-ANSYS → Peak stress

J.-B. Jeanneret

HALO '03

Low Z Materials

Graphite looks best but transverse impedence too high for 25 coll.

Case	Nb. bunches on jaw	Survival deficit factor	
		Graphite	Berylium
$1.3\,\mu s$	20	3	9
$0.7\,\mu s$	8	1.2	3.6
Regular	5	0.75	2.2

J.-B. Jeanneret

HALO '03

LHC Phase I (L=10^{33}) Scenarios

- **Uncoated fiber-reinforced graphite primary & secondary collimators:**
  - Maybe metallic (not Be) in low risk locations
  - Live w/ bad impedence for sake of safety (x10 Be)
  - Conventional (LEP-like) mechanical design
  - Operations:
    - Always to be used at injection & ramp
    - Use during physics running until L ~ few 10% of nominal
  - Cu tertiary collimation at experiments
- **Lattice will reserve space for 2nd "hybrid" phase of secondary collimators**
  - Metallic, Low impedence
  - Useable up to ultimate LHC parameters
  - Possible materials: Cu doped C, Al, Be, Ti, …
 - Rotary design a possible option

R. Assmann

10 June 2003

NLC Collimator R&D Program

- **SLC showed importance of collimator damage and collimator wakefield kicks**
- **SLAC NLC Group:**
  - **Collimation system lattices**
    - TRC 2002 "Collimation Task Force"
      - w/ Nikolai Mokhov & Sasha Drozhdin
  - **Collimator wakefield kicks**
    - Single beam measurements in SLAC Linac Sector 2
    - Analytic calculations
    - MAFIA-style simulations
  - **Material damage studies**
    - "Coupon" tests at FFTB
  - **Design & prototype rotary "consumable" collimators**
  - **R&D program on refreezing liquid metal collimators**

Collimator Damage
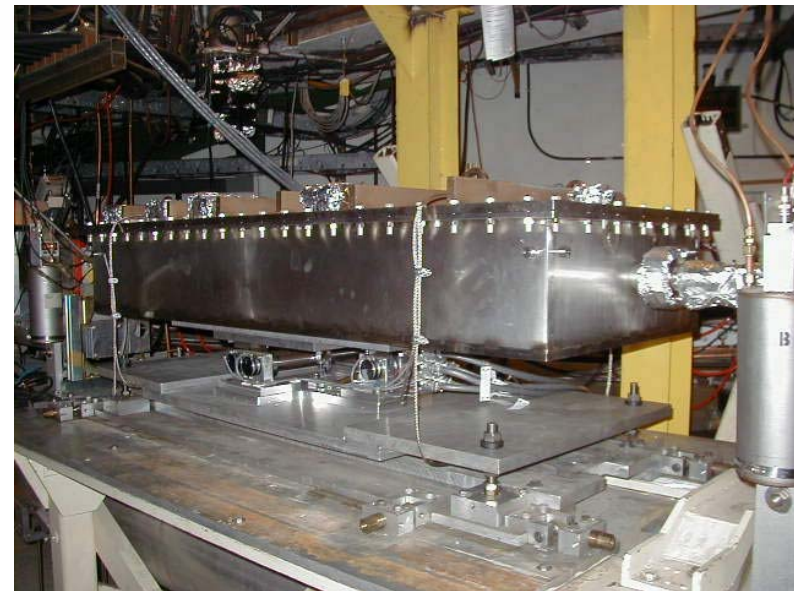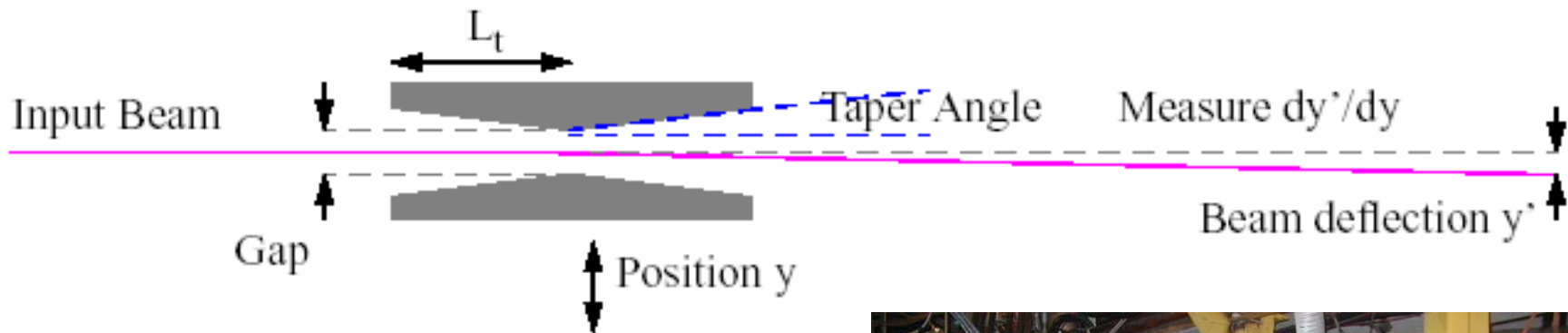
SLC Linac Collimators in 1995: Gold-coated Titanium
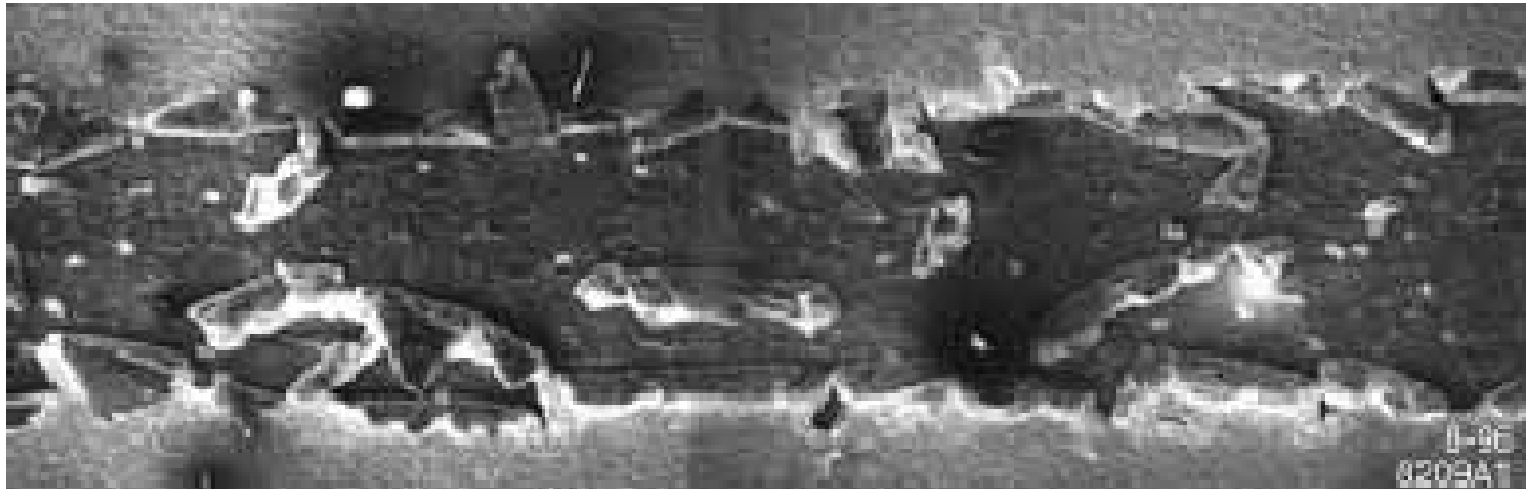
1mm

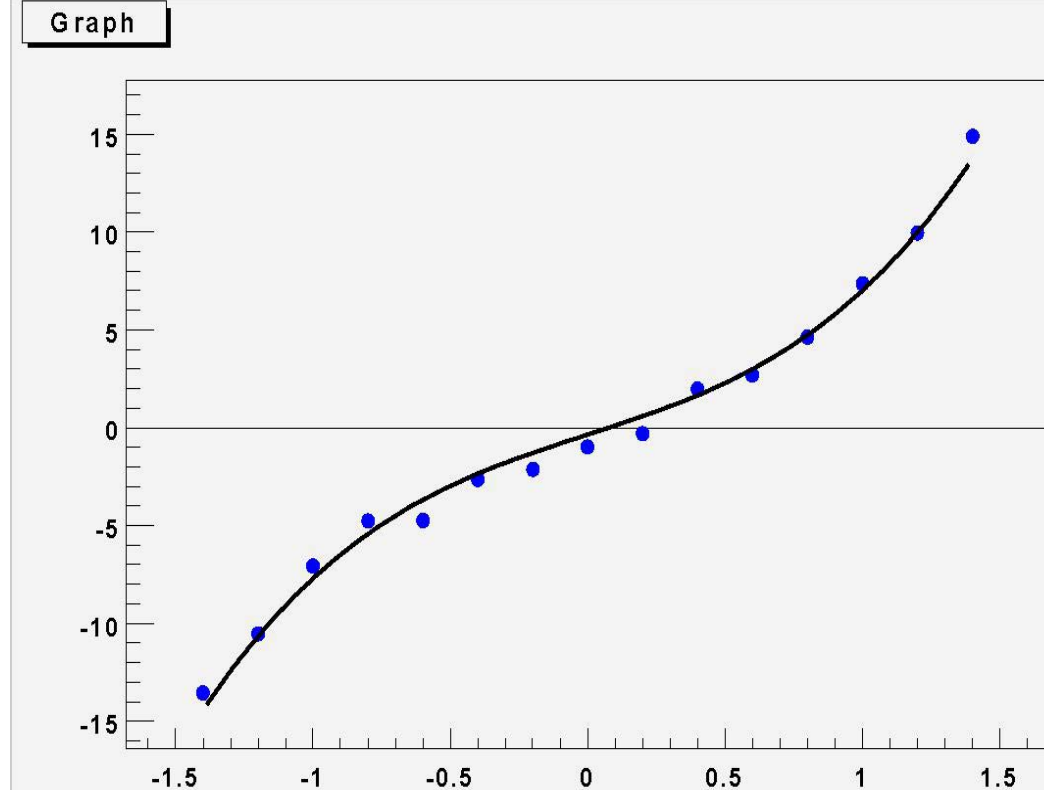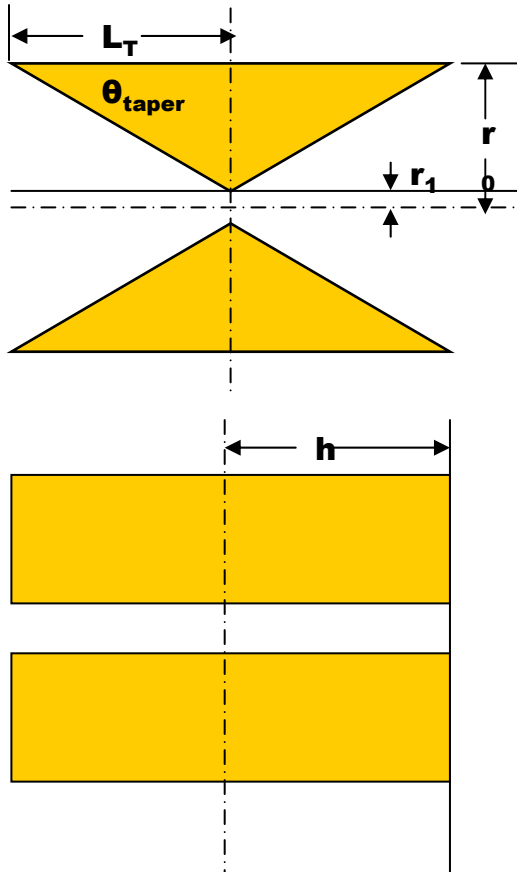Feature size ~250μm

Wakefields x25-50 larger than before damage

Collimator Wakefield Measurements

ASSET: 1.19GeV, 2×10^{10} e$^-$. 650um bunch length, damped beam (300 x 60 um).

Sample Coll-Wake Measurement

Near-Wall wakefield from rectangular collimators

Beam Damage To Materials

Electromagnetic Showers: NLC avoids shower damage by using thin spoilers, and then a long drift before the absorber. 1m Cu = 5.3 RL.

Direct ionization energy loss: ~1.5MeV/(g/cm^2) for most materials. NLC beam size (10x0.5 μm) makes this THE problem; at LHC 200x200 μm is easier.

Collective effects: Damage from I^{2}R heating due to high peak image currents. Can also have damage from direct electric field ionization. This can cause damage without beam interception. Calculations suggest this is only an issue for beams within 50 um of the spoiler surface.

Hadronic showers: A new regime for us. 1m Cu = 2.6 λ_{INT}

There is considerable uncertainty in the beam density levels which produce damage in either a single shot, or in multiple pulses and how material melts or fractures. Simulation work at LLNL could improve damage estimates.
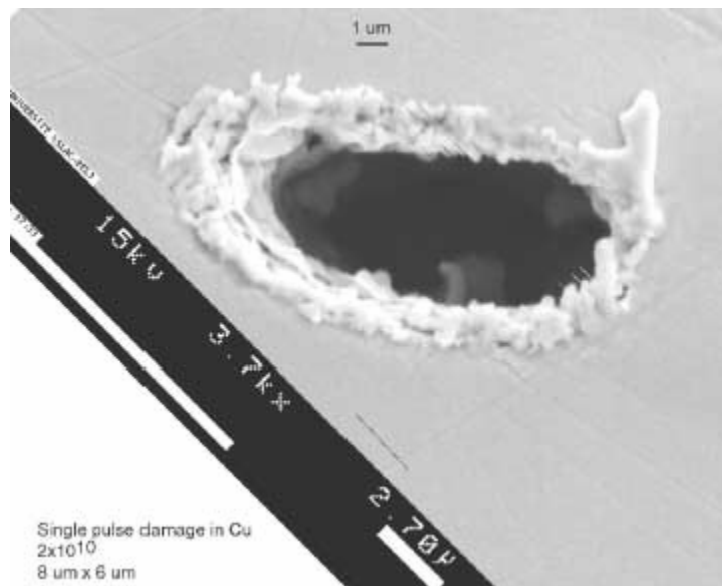
Measurements at FFTB to confirm calculations

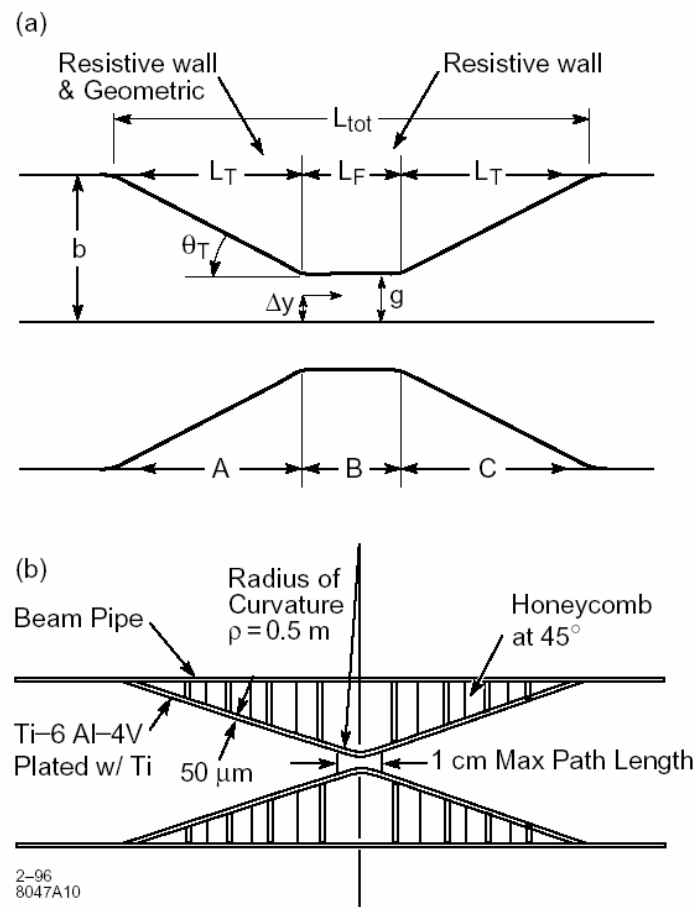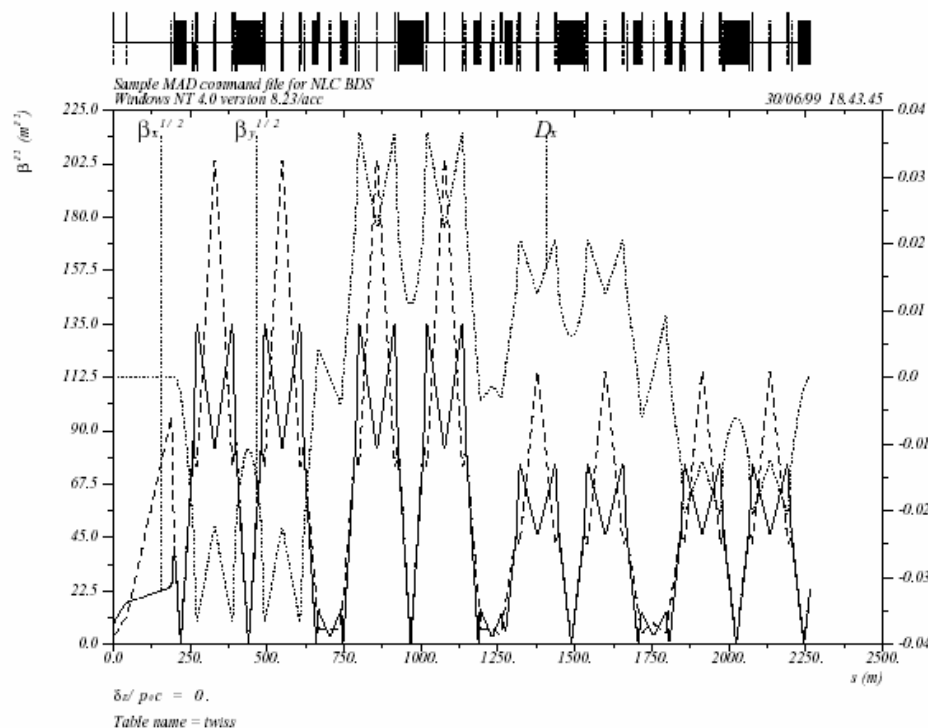Tom Markiewicz

FFTB Coupon Damage Tests

Beam: 30GeV, 3-20x10^9 e-, 1mm bunch length,
σ_{xy}^2 ~ 45 - 200um^2

Test sample: copper, 1.4mm thick. Single pulse tests.

Damage was observed for beam densities > 7x10^{14} e- / cm^2.
Picture is for 6x10^{15} e-/cm^2.

Single pulse damage in Cu
2x1010
8 um x 6 um

1996 NLC ZDR Collimation Lattice had "indestructible" thin spoilers and thick absorbers

- Large betatron function

- Large dispersion

- Large separation between spoilers and absorbers

Tom Markiewicz

PASSIVE Protection Makes for SENSITIVE Lattice

- Long system length (~ 2.5 km per side)
- Several interleaved families of sextupoles for chromatic correction
  - Small bandwidth
  - Tight tolerances, particularly sextupole alignment
- Large $R_{12,34}$ elements from one sector to the next
  - Diurnal Quad Drift of a few μm in one sector would drive the beam into the collimators in the next sector, damaging downstream absorbers
- Interleaved Horizontal Betatron and Energy collimation
  - Many collimators
  - No additional spoilers could be added
  - Wakefields from the collimators were at the limit of tolerability
  - Horizontal collimation depth could not be adjusted independently of the energy collimation depth
- Looser IP- vs. FD-phase collimation in the 2nd pass (strong wakes)
  - Careful control of phase advance, both for on- and off-energy particles, to prevent phase migration
  - Careful control of the chromaticity

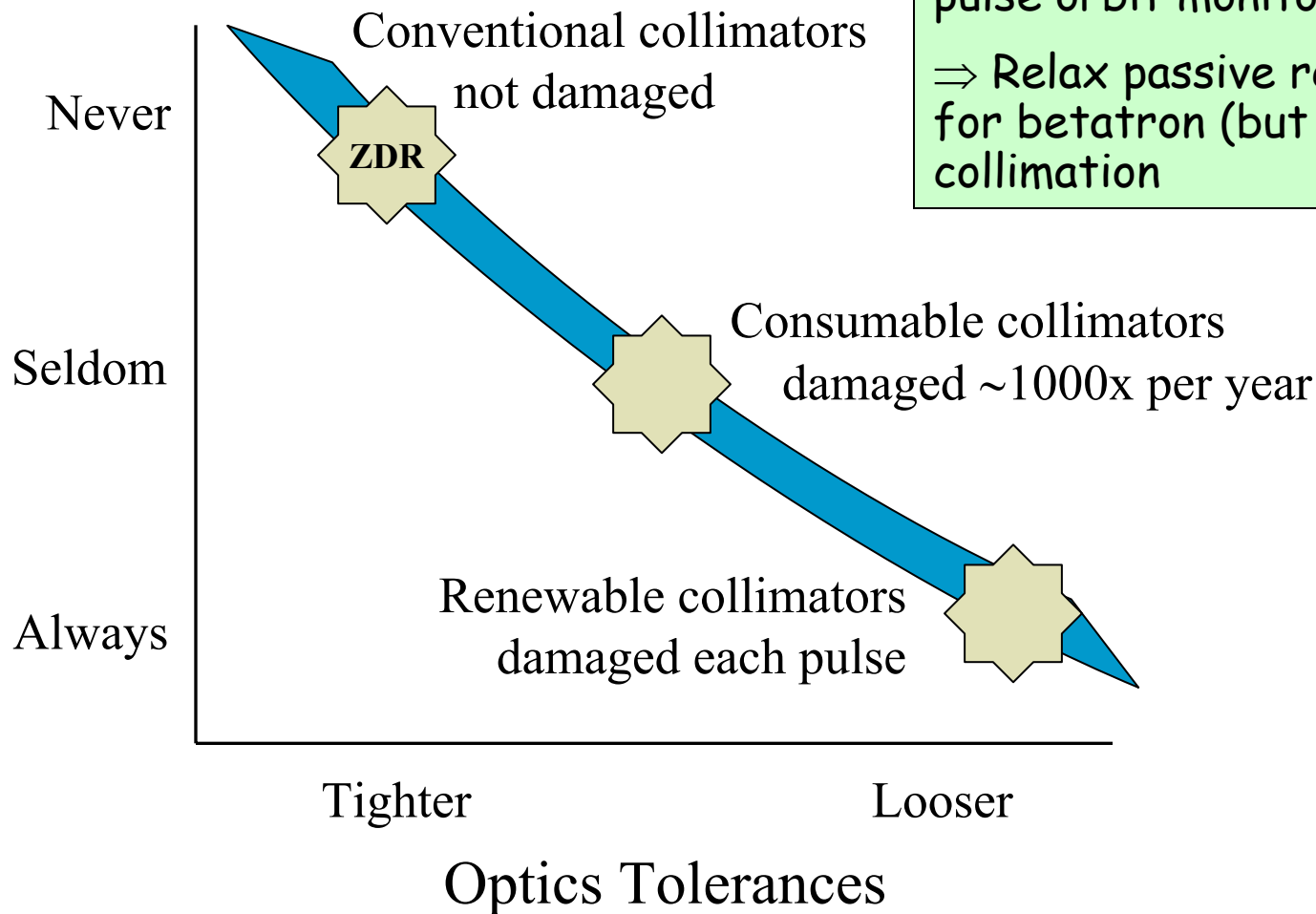LCC-0052, Tenenbaum

Damageable Collimators Share Pain

SLC experience

- Frequent energy errors &/or feedback system problems

- Few catastrophic quad failures
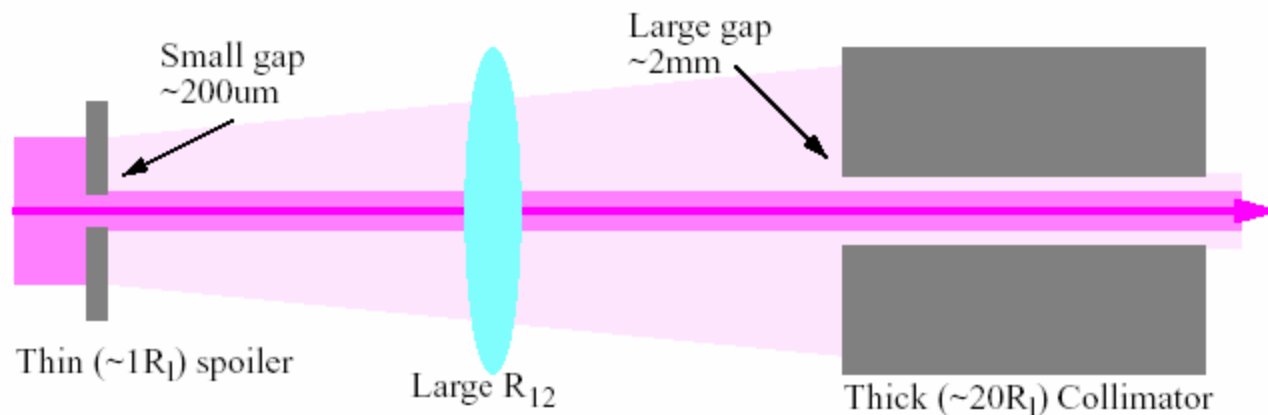
NLC MPS requires pulse-to-pulse orbit monitoring

$\Rightarrow$ Relax passive requirement for betatron (but not energy) collimation

Single Pulse Collimator Damage

Never

Seldom

Always

ZDR

Conventional collimators not damaged

Consumable collimators damaged ~1000x per year

Renewable collimators damaged each pulse

Tighter   Looser

Optics Tolerances

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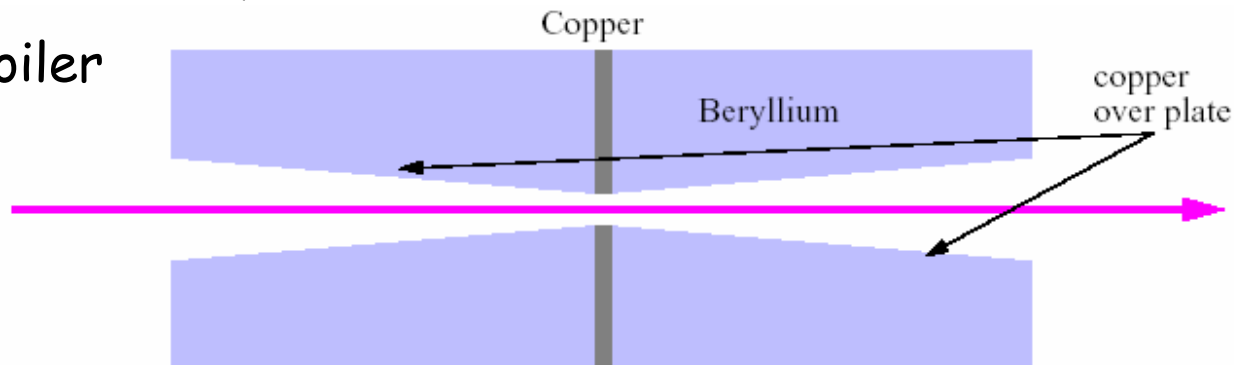# Consumable/Renewable Spoilers

Spoiler / Absorber Scheme

Tapered low resistivity surface for wakefields

Thin hi-Z spoiler
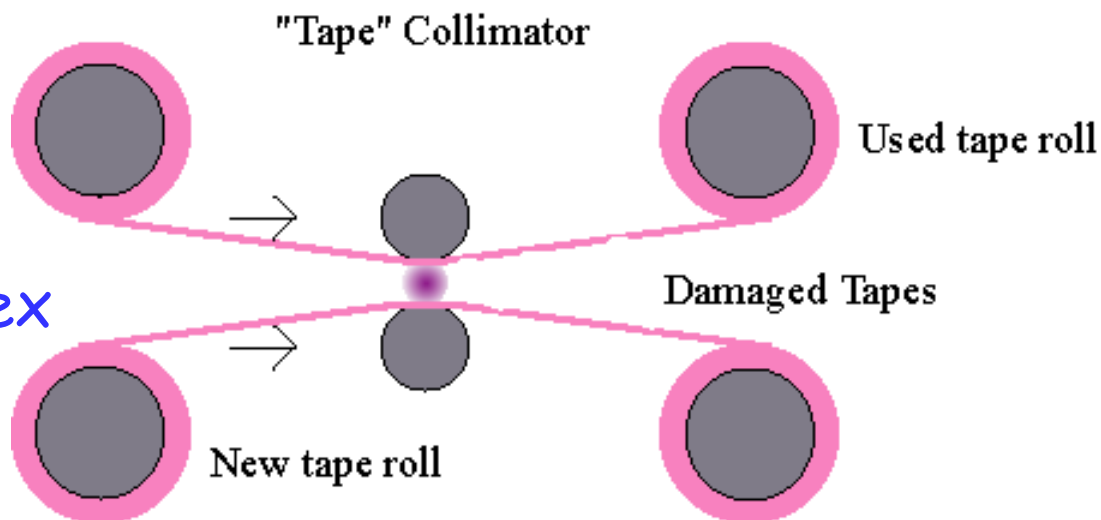
Consumable Options Considered

Rotating "Wheel" Collimator

Rotation

Rotation

Option Chosen

Damaged Area

Too Long

"Bar" Collimator

"Tape" Collimator

Used tape roll

Too complex

Damaged Tapes

New tape roll

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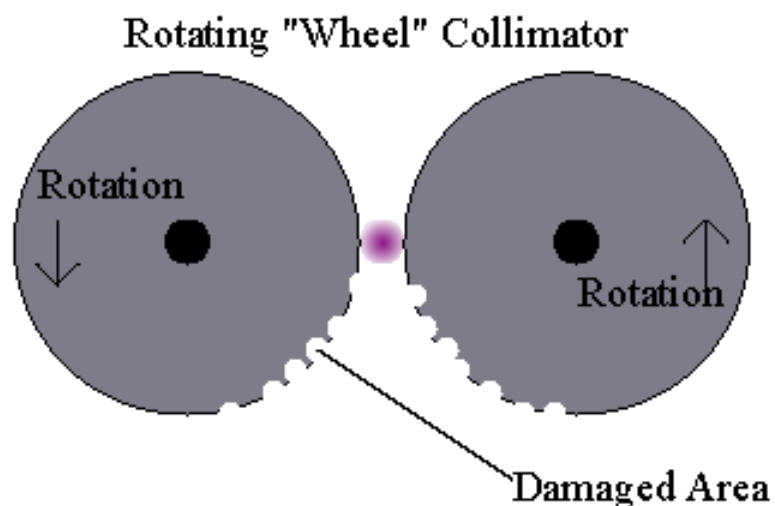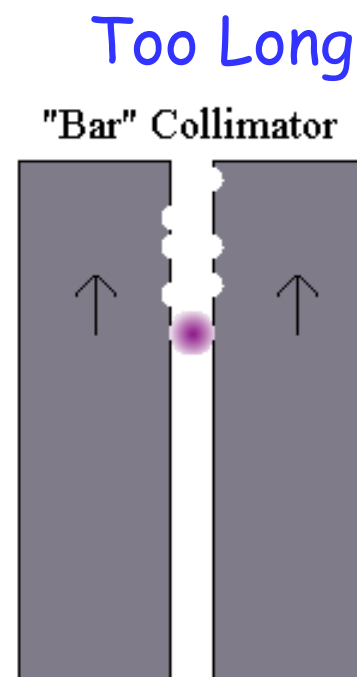
Consumable Spoiler Requirements

Max.# Damaging Hits	**1000**
Length @ Min. Gap	**0.6 rl**
Radius of curvature	**.5 m**
Aperture	**200-2000 μm**
Edge Placement Accuracy	**10-20 μm**
Edge Stability under rotation	**5 μm**
Beam Pipe ID	**10 mm**
% Beam Intercepted per side	**.05%**
Beam Halo Heating	**~0.2 W**
Image Current Heating	**~0.5 W**
Radiation Environment	**10^5-10^6 rad/hour**
Vacuum (tbd)	**<10^{-7} torr**

~30cm diameter

7mm Cu + Be wings

Radiative Cooling

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Rotating Wheel Design Features
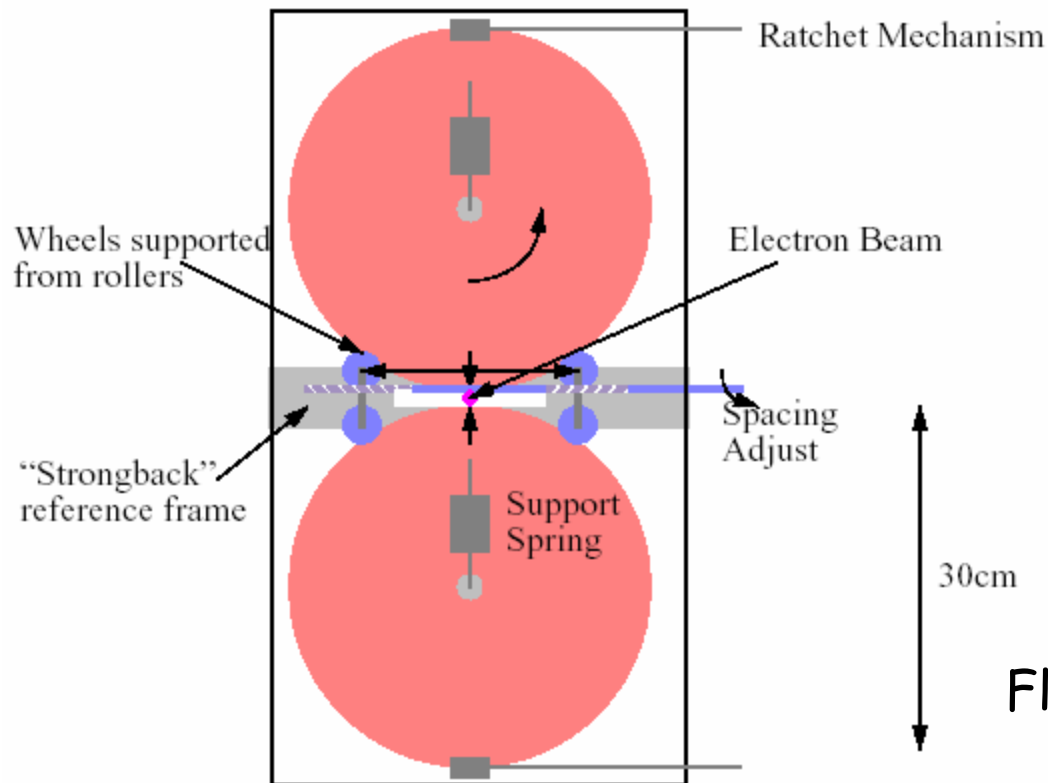
1 d.o.f. internal mechanism referenced to rigid backplane provides aperture
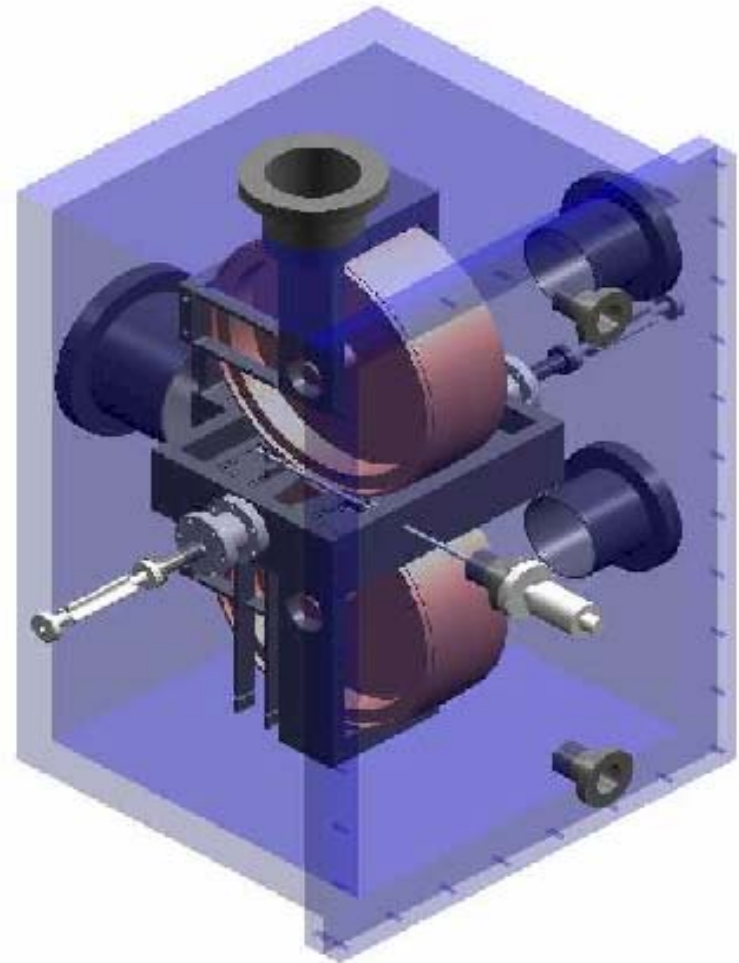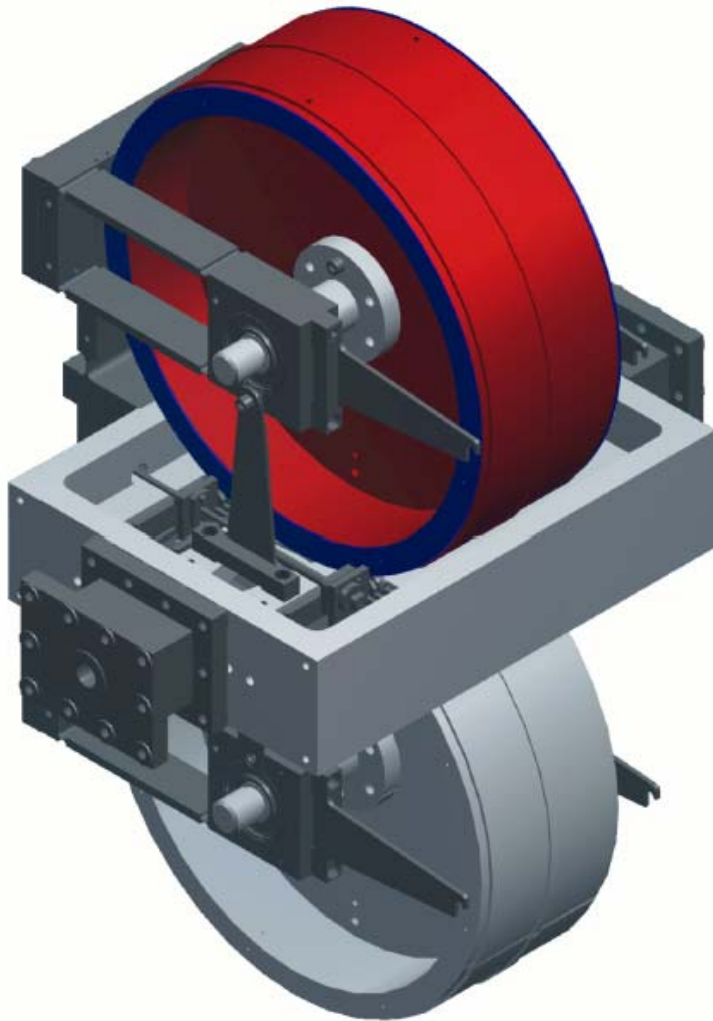
Control through transversely adjustable stops

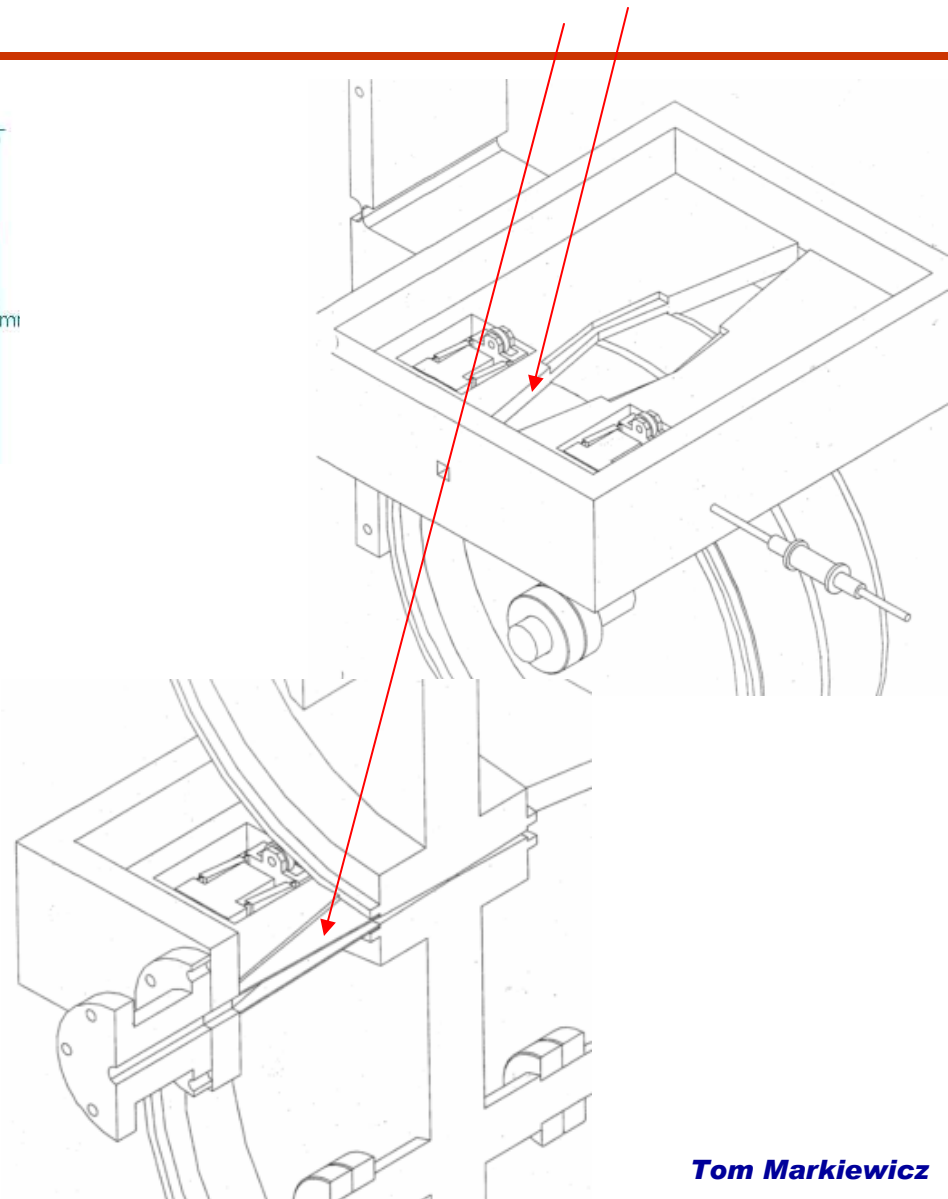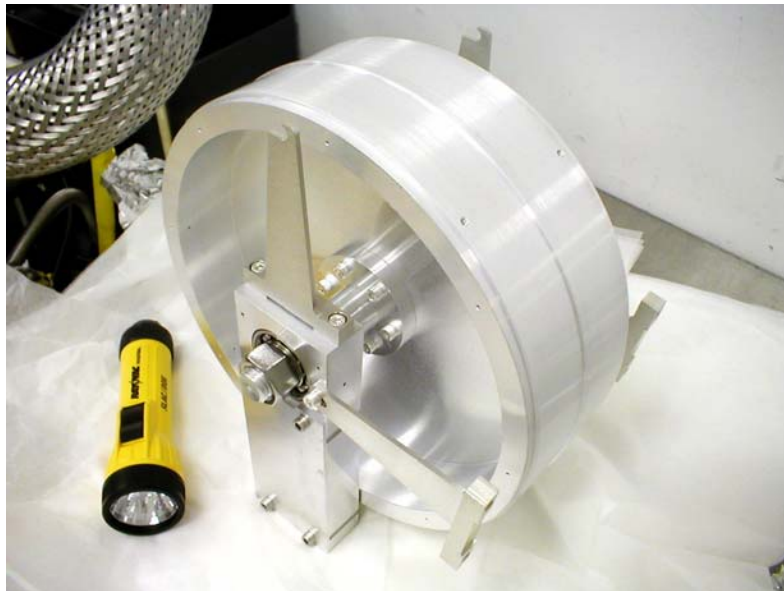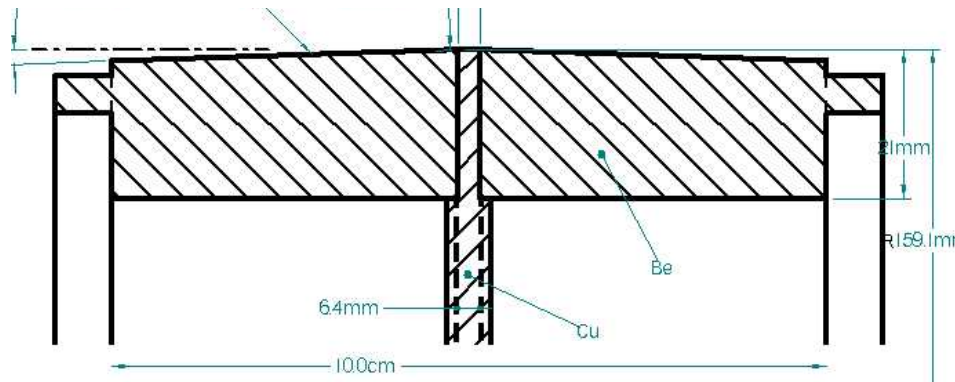Flexure pivots eliminate backlash

Vacuum bearings

Housing aligned to beam via external movers & BPMs

Engineer to minimize thermal effects

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Consumable Spoiler Prototype

Tapered Wheels & Wakefield Wedges

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Adjustment Mechanisms

Wheel Ratchet
& Support
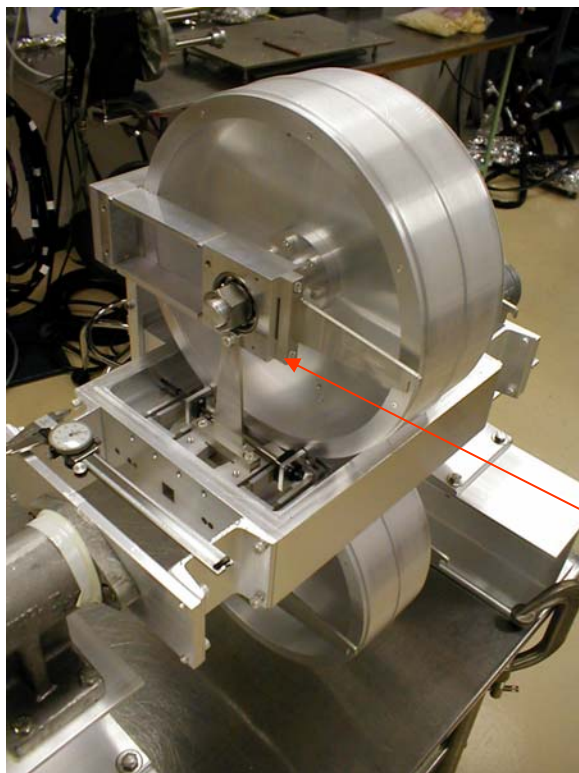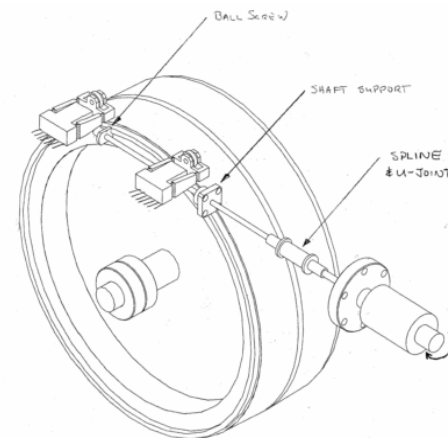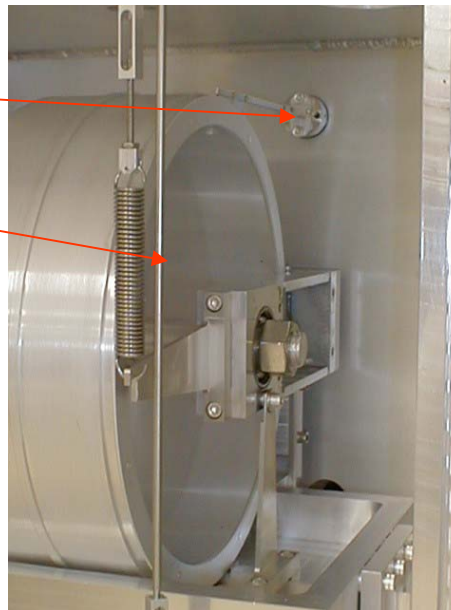
Aperture Adjust
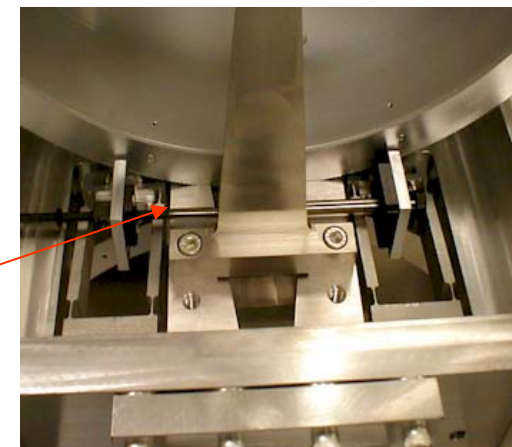
Mounted in Vacuum Vessel

Consumable Spoiler Performance (1)

Stability with Wheel Rotation
~ ±15 μm
Runout in support bearings;
Use higher precision bearings

Motion accuracy ~±15 μm
OK
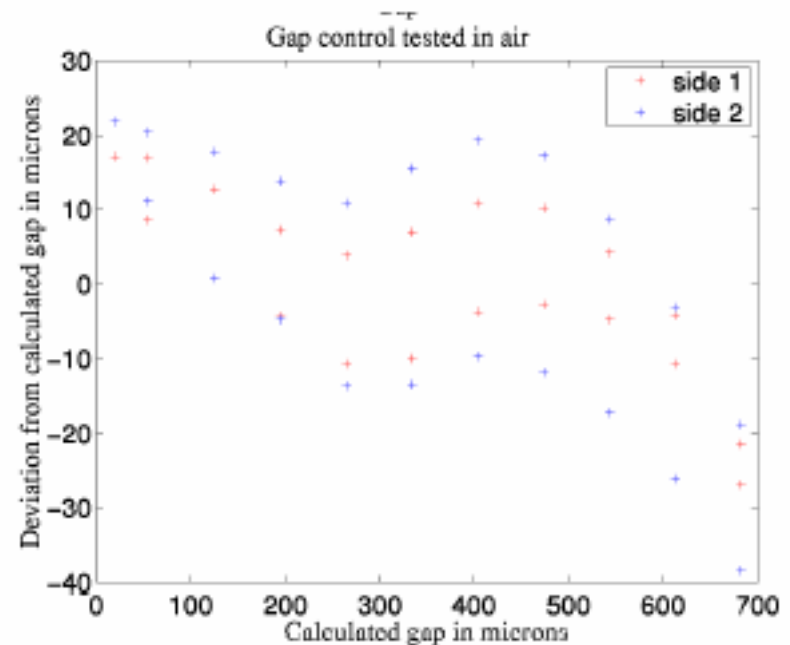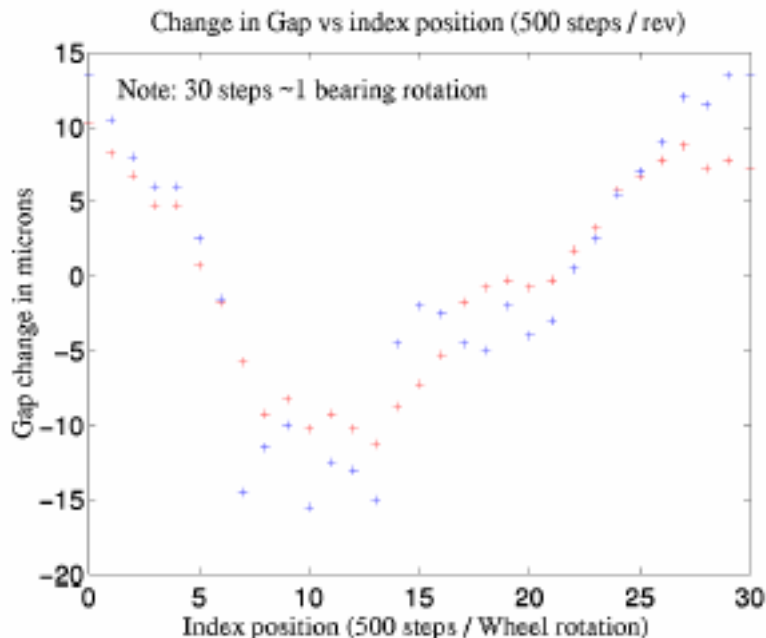
Consumable Spoiler Performance (2)

- Hysteresis in Gap as Wheel Rotated ~25 μm

  - Improve by reducing torque from support springs

- Vacuum 2 x 10^{-7} torr

- Heat performance

3.5W/rotor	10W/rotor	11W/rotor
ΔT=17$\degree$C	ΔT=42$\degree$C	ΔT=46$\degree$C
5/250 μm	8/250 μm	15/250 μm

LHC Phase II Collimator Specs
NLC-like but Larger, Heavier & Cooler

Length   ~1m "Light" material <~0.5m Cu
Material & Wakes   Presumably metal, needs study
Gap   ±5-10 σ ~ 200-400 μm
Alignment   10%σ ~ 20 μm ?
Vacuum   UHV, in situ baked to 250°C
Radiation Hardness   Inorganics Only
\# Accidents Allowed   5
Power

   Accident   8x1.15E11 protons
   Peak Loss 10^{11}p/s$\equiv$30kW (Assmann: 4E11=120kW) over 10s
   Steady Loss   3x10^9p/s $\equiv$1kW (Assmann: 8E10=27kW)
Cooling   Several kW within 1cm of surface
\# Required   5-10 (Horiz. high risk) of 30 total Phase II Hybrids
Transverse space   ?
Reliability   ?

> So far, numbers from email exchanges
>
> Needs study

Tom Markiewicz

Proposal on the Table

1. **Develop a prototype rotating collimator with cooling and appropriate length/materials for the LHC Phase-II**

2. **Measure short and long-range wakefields from LHC Phase-I collimators using the COLWAKE facility**

   - **Long-range wakes measured by single beam kicks in linac BPMs as function of collimator-beam separation for collimators of different shape, resistivity & surface roughness**

   - **Upgrade to "ASSET" style operation where trailing bunch measures short-range wake due to leading bunch as function of bunch separation**

3. **Perform material damage studies on LHC Phase-I collimator materials in SLAC FFTB coupon test facility**

Definitions

- **P0: Existing prototype**
- **P1: Inner Mechanism of Mechanical Prototype of LHC Collimator**
  - **Use UHV components**
  - **Do NOT use exotic materials (e.g. Be)**
  - **Measure mechanical performance in air w/ heating/cooling**
- **P2: UHV Version of P1**
  - **Measure mechanical perf. in UHV w/ appropriate Heating/cooling**
- **P3: UHV Version with exact materials for beam tests of wakefields & damage**
- **P4: DFM version for industry**

Guesstimated TimeLine & Resource Requirements

2004	2005	2006	2007	2008
Coupon Tests COLWAKE	Coupon Tests COLWAKE	X	X	X
Finish P0 Specifcations •Lattice •Materials	Design P1 Build P1 Test P1 Design P2 Build P2	Test P2 Design P3 Build P3	Build P3 Test P3 Design P4 Build P4	Construct 5-10 Collimators
$75k M&S + Shop	$25K+125k+ 75k=$225k	$400k	$500k	$100k/each
0.5 ME 0.5 SLAC P 0.25 FNAL P	1.0 ME 0.5 SLAC P 0.25 FNAL P 1 M. Des.	1.0 ME 0.5 SLAC P o.25 CTRLS 1 M. Des.	1.0 ME 0.5 SLAC P o.25 CTRLS 1 M. Des.	

Tom Markiewicz

END

Extra slides follow

Collimator Material Properties

Material	R_l cm	Temperature Limit °C	Beam density 10^{14} e⁻/cm²	Damage radius at 10^{12} e⁻ um	Damage radius at 10^9 e⁻ um
Copper	1.4	180	3.4	215	6.8
Titanium	3.6	770	16	100	3.2
W/Re	0.35	700	5.4	176	5.5
Molybdenum	~1	500	5.2	174	5.5
Beryllium	35	400	29	74	2.3
Carbon	19	2500	87	43	1.4